HEURISTICS FOR SCIENTIFIC AND LITERARY CREATIVITY: THE ROLE OF MODELS, ANALOGIES, AND METAPHORS*

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1. Origins of the idea of creation and creativity

The concept of creation in Western thought has meant the act of bringing into being what was previously part of non-being. This concept can be traced at least to the medieval notion of God, the creator, bringing into existence our universe *ex nihilo*. Man was not associated with the process of creation except possibly in the arts. But even in the arts and literature, at least until the Renaissance, the artist and writer were viewed not as individuals who bring into existence forms that previously did not exist, but as persons who replicate forms found in nature. Representational art was precisely what the word signifies, a picturing of something that was already there to begin with. Likewise, in Greek literature the dominant idea was that the Greek dramatists recreated stories that were part of their cultural heritage. Aristotle called such recreation *mimesis*, which meant that tragedy was an imitation of action, an imitation of actual life.

The concept of discovery, on the other hand, brings to mind the uncovering of something that was hidden from view but was part of the real world all the time. Many methods were proposed by philosophers and scientists for uncovering the real. In spite of the fact that classical epistemological theories did not utilize the concept of either creation or discovery, they were all candidates for a type of logic of discovery.

2. Why did traditional epistemologies conspire to keep the problem of creativity submerged for so long?

The story of how the concept of creativity gained a foothold in philosophy and science is a complex one. For the most part until the twentieth century there was little or no room for the idea of "creativity" in philosophy or science. In

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philosophy epistemological theories promised indubitable knowledge of being, at least in metaphysics in such philosophies as Platonism, Aristotelianism, Thomism, Cartesianism, Hegelianism, Marxism, Phenomenology, and others.[1] There are exceptions to the above philosophies, but they are not part of the mainstream of philosophy.[2] In these theories knowledge acquisition was reduced to a method with the result that the concept of creativity was not needed as a category of explanation. Discussion of creativity could be damaged or completely squashed either by reducing methodology to a mechanical procedure or by insisting that one has or should have demonstrable proof when it comes to the question of justification (i.e. Galileo).

For purposes of illustration I will highlight only a few of these epistemologies. For example, concerning the medieval philosophies it can be said that God was the creator, man was a contemplator. The goal of man was contemplation of the eternal verities and the pursuit of wisdom. Even happiness was defined by Aristotle and St. Thomas Aquinas in those terms. The task of the knower was to reflect reality rather than to create anything in the process of knowing. For example, in the Aristotelian-Thomistic epistemology knowledge of the world was guaranteed by the powers of the mind, specifically the powers of abstraction.

Enough high-powered machinery was packed into the head to guarantee indubitable knowledge of the world. Universal concepts presumably derived from individuals by the process of abstraction were claimed to reflect accurately the nature or essence of individuals. The mind has the power to drop the accidental properties of individuals and concentrate on the characteristics common to all the members of certain species (e.g., humans: rationality and animality). Creativity, if discussed at all in such a framework, was relegated to the realms of music, art, and literature. All one had to do to arrive at knowledge of the world was to follow carefully the procedures of abstraction. The problems with the theory of abstraction are well known. Because there are similarities between any two randomly selected objects, the main problem for any theory of abstraction is to explain how one is to choose those similarities which define a set of objects as members of a certain natural kind.

There is another reason why creativity and science do not intersect for Aristotle. For him "scientific" knowledge was a purely deductive discipline governed by the rules of valid syllogisms.[3] Whatever ingenuity or creativity was necessary went mostly into the requirement of reducing all valid syllogisms to the first figure. I do not want to deny that deductive proof at times requires creativity. However, the type of creativity called for does not pose the central and deepest problems of creativity.

The topic of creativity in science could have surfaced with the rise of modern science but it was blocked, by Newton of all people, who insisted that he derived the laws of physics from nature.[4] The problem is that the concept of

derivation as I mentioned above does not allow for the most interesting questions of creativity to surface. Derivation as normally conceived is a matter of following rules of valid inference from higher principles. Newton's insistence that he derived the laws of physics from nature has puzzled philosophers and scientists alike. The puzzle arises when one realizes that nature does not consist of propositions or principles and hence derivation in the logical sense is not possible.

Inductivist methodologies of science that began with Francis Bacon were an improvement over the Aristotelian or the later Newtonian accounts of how original hypotheses and theories were created. Still the inductivist accounts of science were a mixed blessing. Overall they probably had a stifling effect on questions of creativity or discovery in science. The emphasis on fact collecting as a preliminary starting point of scientific investigation was a misplaced task since random fact collecting cannot lead to fruitful inductions. As Hempel[5] and othere have pointed out, what the inductive method lacks is a criterion of relevance. Which facts should be collected? Certainly not all facts are relevant. Not even the formulation of the problem provides an adequate guide for fact gathering. Furthermore, the classification of facts presupposes some system of categories, a point which the inductivist tends to hide rather than illuminate. Finally, even if the above problems are solved the payoff is rather limited. True, enumerative induction can account for the creation of low-level generalizations, or, as they are often called, empirical laws of science.[6] Unfortunately inductivists are imperialists who want to generalize induction as an explanation of all science. Here the position usually called "inductivism" runs into serious problems. I have yet to see an explanation, on inductivist grounds, of Newtonian physics, or of the Einsteinian theories of relativity. An imaginative defense of a form of inductivism can be found in Mary Hesse's book *The Structure of Scientific Inference*. I am, however, skeptical that induction can explain the appearance of such original theories as Einstein's general theory of relativity.[7]

The empiricist climate was not very conducive to raising questions of creativity either in science or in literature. Part of the problem was the view, as in John Locke, that all ideas were derived either from sensation or reflection (upon the activites of the mind) or were complex ideas. Such a framework restricted the role of imagination in the formation of novel theories, which had far-reaching implications for prediction and explanation. Furthermore, in the realm of literature such a framework did not allow for an adequate account of metaphor.[8]

The major problem with the empiricists is the much too stringent claim that all *bona fide* ideas must originate in sensation. Couple this requirement with the view that the mind is passive in sensation and there is little room, if any, for the creative imagination in the generation of novel ideas.

With the rise of neo-positivism in the first quarter of the twentieth century, questions of creativity and discovery fared no better than with the classical empiricist position. The dominating theme of this period was the distinction (introduced by Hans Reichenbach) between the context of discovery and the context of justification.[9] Within this context questions of discovery in science were relegated to psychology, while questions of theory justification belonged to philosophy. Because discovery and creativity are closely related questions, creativity in science on this view was also relegated to psychology. I will argue for bringing back into philosophy problems of creativity and discovery.

An equally formidable stumbling block to the formulation of the problem of creativity in science can be found among some of the early Marxist-Leninists. I have in mind here primarily Lenin's famous epistemological treatise *Materialism and Empirio-Criticism*.[10] Ideas, in Lenin's view, are mirror images of objects in the world. When they reflect accurately objects in the outside world, they provide us with windows on the world. There is an inescapable causal link between the world and ideas in our consciousness. Such a view has the advantage that it can explain the realist beliefs held by many scientists, but at what price?

It is now commonplace to see the history of science as a sequence of incompatible theories. If one couples this view with the observation that subsequent theories drop some concepts and adopt others (e.g., phlogiston-oxygen), then what sense is there to the view that concepts reflect the world? One could say, following Rorty's ironic metaphor in *Philosophy and the Mirror of Nature*, that the mirror has to be polished further in order to reflect better. Unfortunately for Lenin's theory such a reationalization quickly loses its force with repeated use. In summary it can be said that Lenin's view on concept formation seriously underestimates the role of the creative imagination in the formulation of novel concepts and theories.

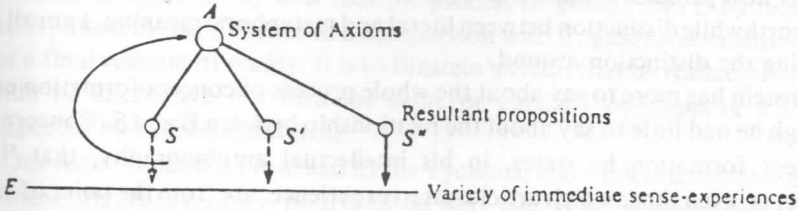
3. Creativity and Einstein's philosophy[11]

Einstein was one of the first thinkers to have developed a philosophy especially conducive to discussions of creativity in science. He rejected pure versions of both empiricism and rationalism. His philosophy comes closest to a kind of Kantianism, without the *a priori* element.

a. *Einstein's model of theory construction*

A hint of Einstein's epistemological position may be found in a letter Einstein wrote to his longtime friend Maurice Solovine.[12] There, Einstein provides a

useful scheme which represents the knowledge-seeking enterprise (see Figure 1).



If one were to begin from the psychological perspective of the scientist engaged in theory construction, then one should start with the plethora of human experiences represented by the base line marked "E." It is clear from Einstein's writings that by this experiential base he does not mean uninterpreted givens but the whole richness of our experiences, including those which are acquired as a result of using sophisticated instrumentation (e.g., the observations that were made of the bending of star light during an eclipse of the sun). From such a potentially infinite set of experiences the scientist makes a bold creative leap, represented by the upward arrow, which I will call "J," to the axiomatic assumptions, which Einstein labels "A." There is no logical method for arriving at these axioms. According to Einstein "the scientist has to worm these general principles out of nature,"[13] but in another place he says, "only intuition, supported by being sympathetically in touch with experience" can reach them.[14]

From these general axioms, statements are logically deduced (here called "S") which are then compared with the experiential base "E." In this model Einstein speaks of concepts only at the level of assertions which are deductive consequences of the axioms. Also he feels that the relationship between the concepts in the assertion and the sensory experiences is "not of a logical nature." What is the force of this denial? He does say that as a matter of fact this relationship between the concept and the direct experience is pragmatically certain. Also he emphasizes the fact that the relation between a concept in "S" and "E" is much more certain than the far more removed relationship between the axioms and the experiential base. For fields like theology Einstein claims that since there is no contact with experience they "would be of no value at all for the 'comprehension of reality'."[15] Einstein's intention here is to underline clearly the importance of the empirical-experimental component in attempts to comprehend reality. He seems to require that any claims of knowledge about the world have an experiential connection.

But this does not explain what the relationship between the S's and the experiential base is. Mary Hesse has suggested that this relationship is

metaphoric in the case of theoretical explanations.[16] Others have gone so far as to suggest that all of language applies to the world metaphorically. No matter how persuasive this latter suggestion is, the problem is that it obliterates the worthwhile distinction between literal and metaphoric meaning. I am all for keeping the distinction around.

Einstein has more to say about the whole process of concept formation even though he had little to say about the relationship between E and S. Concerning concept formation he states, in his intellectual autobiography, that "All concepts, even those which are closest to experience, are from the point of view of logic freely chosen conventions."[17] According to Einstein, concepts have a fictitious character. They are constructs and inventions rather than discoveries. But, if concepts are freely chosen conventions, if they have a conventional character, then indeed there is no logical deductive or even inductive path from the sensory experience to the concept. Actually Einstein wants to go even further. Not only are the concepts not derivable by deductive or inductive methods from experience, but neither are the laws and axioms of theoretical systems. Einstein wrote:

> A clear recognition of the erroneousness of this notion came only with the general theory of relativity which showed that one could take account of a wider range of empirical facts, and that too in a more satisfactory and complete manner, on a foundation *quite different from the Newtonian*. But quite apart from the question of the superiority of one or the other, the fictitious character of fundamental principles is perfectly evident from the fact that we can point to two essentially different principles, both of which correspond with experience to a large extent; this proves at the same time that every attempt at a logical deduction of the basic concepts and postulates of mechanics from elementary experience is doomed to failure.[18]

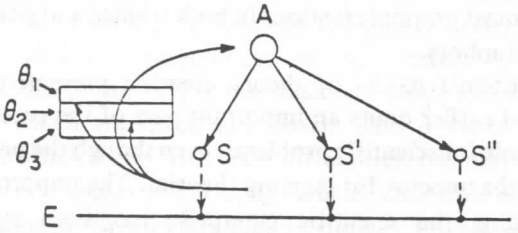
Einstein gives us here an important insight into the whole process of creativity in science. Implicit in Einstein's model of theory-creation is the fictitious character of the fundamental principles of any deep theory about nature. Furthermore, since it is possible to have more than one fundamental principle or theory compatible more or less with experience, the problem of theory choice is raised. For if there is no deductive or inductive method for hypothesis or theory-creation and if fundamental principles have a fictitious character, then we have the problem of how to choose among a group of competing theories that which is epistemically better. For a deductivist or an inductivist there is no problem with the justification of the chosen theory, since the logic of theory-generation functions as well for justification. Their answer is simply that their principles were derived from the data.

b. *Some extentions and problems with Einstein's model*

It should be apparent by now that the process of going from E by means of J to A, down to S and thence to a comparison with E, guarantees neither truth nor a final account of reality. It is to Einstein's credit that he realizes that there could be alternative A's with the same or partially overlapping S's, each supported by experimental data.

One such situation is presented by the Tychonic and Copernican theories, Up to the seventeenth century, both theories were almost equally supported by the same observational data. The clinching observation in favor of the heliocentric theory, the observation of parallax, was not made until 1828. But by this time most of the scientific community had been persuaded to switch to Copernicanism. Obviously more was at work than simple agreement with the data.

Schematically this extention of Einstein's original model might be represented as follows:[19]



In order to explicate adequately Einstein's position on theory selection one must introduce the aim or goal of science. Only if we are clear on the goals of scientific theories can we hope to evaluate theories adequately. The EJAS model misleadingly suggests that the sole goal of science is to create theories that get confirmed in experience. It is true that the connection with experience, with experiment, is a component of good theory in modern science but for Einstein it is just one of the components of good scientific theory. For several reasons it cannot be the only requirement. In the first place, the class of theories that can satisfy this requirement is unlimited,[20] and in the second place this is not the goal of science. The goal is the comprehension of reality, not just prediction of events. Let me quote Einstein at length on this important point:

> It is, of course, universally agreed that science has to establish connections between the facts of experience, of such a kind that we can predict further occurrences from those already experienced. Indeed, according to the opinion of many positivists the completest possible accomplishment of this task is the only end of science. I do not believe, however, that so elementary

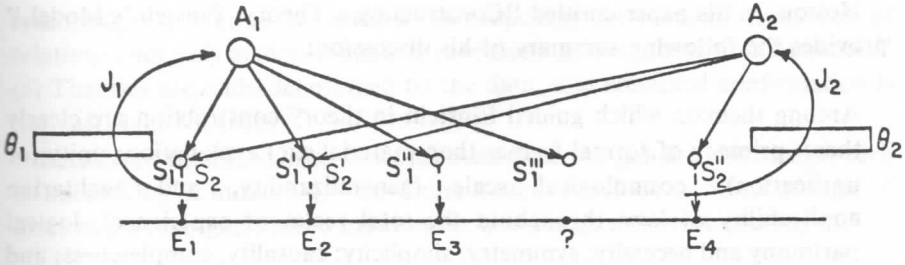
> an ideal could do much to kindle the investigator's passion, from which really great achievements have arisen. Behind the tireless efforts of the investigator there lurks a stronger, more mysterious drive: it is existence and reality that one wishes to comprehend . . .. When we strip [this] statement of its mystical elements we mean that we are seeking for the simplest possible system of thought which will bind together the observed facts . . .. The special aim which I have constantly kept before me is logical unification in the field of physics.[21]

In this passage Einstein hits upon one of the central themes of creativity in science, namely, the unification or binding together of observed facts, of experiences. This tinding together of phenomena which, prior to the binding appeared as disparate, as belonging to different categories, is a mark of a promising theory in science – provided that it satisfies other inner and outer perfections of theories. The binding together of objects from different categories is also the stuff out of which a type of metaphor is created in poetry, what Max Black has called the interaction view of metaphors.[22] It is possible to describe the most original creations in both science and poetry by using such models and metaphors.

Actually Einstein's model of theory creation presented in the letter to Solovine quoted earlier omits an important part of the enterprise of science. It provides no role for scientific problems, even though the problem gives more often than not the impetus for creating theories. The importance of problems for understanding the scientific enterprise has been stressed by many philosophers and scientists. Larry Laudan[23] is the most recent defender of the important role that problems play in our understanding of science. Laudan distinguishes at least two kinds of problems – empirical and theoretical. If the problem is empirical, as in the case of an anomalous observation (e.g., Roentgen and exposed photographic plates; Lavoisier and the gain in weight by an element which underwent combustion, under the phlogiston theory), then the problem arises in the data base "E." If the problem is of a theoretical nature, then it would be located at the top of Einstein's model.

Besides saying that the scientist has to make a creative leap (represented by "J") to the theory, we need to add to Einstein's model another element of which he speaks in other contexts. I have in mind here what Holton has called "themata," or what Einstein termed "inner perfections of a theory."[24] These inner perfections function as a filtering mechanism on the outputs of the creative imagination which generates the hypotheses and theories.

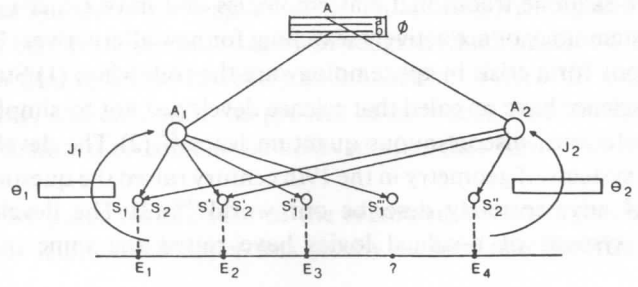
Holton is inclined to put these themata (Θ) as a screening mechanism for the proposed hypotheses and theories in the middle of the upward "J."



I do not want to deny this as a possible interpretation and extension of Einstein's model, based on Einstein's practice as a scientist. But I do think that in Einstein's philosophical writings he also wants to use these criteria as a filtering mechanism which strains out the less adequate of competing theories. That Einstein wants to look at these criteria more in the context of theory-selection and evaluation than in the context of theory-creation is clear from his autobiographical notes.

> The second point of view is not concerned with the relation to the material of observation but with the premises of the theory itself, with what may briefly but vaguely be characterized as the "naturalness" or "logical simplicity" of the premises (of the basic concepts and of the relations between these which are taken as a basis). This point of view, an exact formulation of which meets with great difficulties, has played an *important role in the selection and evaluations of theories since time immemorial* . . .. Furthermore, among theories of equally "simple" foundation that one is to be taken as superior which most sharply delimits the qualities of systems in the abstract (i.e., contains the most definite claims) . . .. The following I reckon as also belonging to the "inner perfection" of a theory: We prize a theory more highly if, from the logical standpoint, it is not the result of an arbitrary choice among theories which, among themselves, are of equal value and analogously constructed.[25]

The model that Einstein has in mind in the above passage would put these inner perfections of a theory at the top.



Holton, in his paper entitled "Constructing a Theory: Einstein's Model," provides the following summary of his discussion:

> Among themata which guided Einstein in theory construction are clearly these: primacy of formal (rather than materialistic) explanation; unity (or unification); cosmological scale (generalizability, and egalitarian applicability of laws throughout the total realm of experience); logical parimony and necessity; symmetry; simplicity; causality; completeness; and of course constancy and invariance. It is adherence to themata such as these which explains in specific cases why he would obstinately continue his work in a given direction even when testing against experience was difficult or unavailable.[26]

Implicit in Einstein's discussion of these themata or criteria was a certain strategy as well as a certain ranking of these criteria. Unfortunately Holton does not try to reconstruct the model of rationality implicit in Einstein's reasoning.

In a series of recent papers Thomas Nickles[27] argues for a similar role of a filtering mechanism for proposed solutions to problems, which he calls "constraints". He states "the constraints, in thus rstricting inquiry, normally provide a heuristic guide or directive. In short, a problem itself more or less points the way to its solution."

Despite the fact that Einstein's philosophical position is conducive to discussions of creativity in science, he still says precious little about the creative process itself nor does he indicate how the creative process belongs within epistemology. Einstein, nevertheless, has to be given credit for anticipating, by at least twenty years, the revolutionary philosophies of Thomas Kuhn and Paul Feyerabend, which are also so amenable to discussions of creativity and discovery. In Einstein's writings we can find many of the theses which later shocked the philosophical community in the sixties, such as the theses that observations are theory-laden; that there is no method for arriving at imaginative theories, that theoretical pluralism is a fixture of the scientific enterprise.[28]

Many reasons can be given for the fact that philosophers and scientists have begun to re-examine traditional epistemologies and have either given up the idea of epistemology or are actively searching for new alternatives. High on the list of reasons for a crisis in epistemology are the following: (1) Studies in the history of science have revealed that science developed not by simple accretion but by revolutions, discontinuous quantum leaps.[29] (2) The development of alternative systems of geometry in the 19th century raised the questions: Which of them, if any, correctly describe our world?[30] (3) The development of alternative systems of n-valued logics have raised the same question for

reasoning. (4) Studies in cultural anthropology have raised questions of relativism not only in morals but also in reasoning, metaphysics, and science.[31] (5) Theories are underdetermined by the data, and empirical confirmation is not sufficient for truth.[32]

Because of these and other reasons, metaphors for gaining knowledge, such as uncovering or mirroring,[33] are under attack. Previous accounts of logic of discovery which guaranteed indubitable knowledge have to be scrapped.

4. Thomas Kuhn, scientific revolutions, and creativity

In spite of the fact that Einstein anticipated many of the outlines of the new epistemology proposed later by Kuhn, Einstein's model is still static. It was Kuhn who supplied the framework within which revolutions in science could be described and at least in part understood. Kuhn distinguished the following developmental stages of science: (a) pre-science stage, what Feyerabend called theoretical pluralism; (b) normal science, where one paradigm-theory becomes dominant; (c) crisis, when difficulties are encountered and, if recalcitrant to explanation after repeated attempts, are called anomalies: (d) theoretical pluralism, where the resultant crisis ultimately leads to an atmosphere in which alternative theories are encouraged to attempt to explain the anomaly; (e) normal science, where one of these proposed embryonic theories ultimately gains acceptance and in time becomes entrenched as the next dominant paradigm-theory.[34]

Marx Wartofsky, in a recent article on creactivity, says of Kuhn:

> He failed to explain why such changes took place; and like the older philosophers of science, Kuhn also left the nature of creativity in scientific thought untouched though he fully took into account its subsequent role in science. Thus, the logical empiricists, the Popperians, and Kuhn left the question of scientific discovery to one side. They assumed it, but none of them attempted to analyze it nor to explain it. In fact, like Polanyi, Kuhn left the process of scientific change to the domain of the non-rational, if not indeed the irrational. And at least in his earlier versions, Kuhn could speak of 'paradigm-shifts' as 'leaps of faith,' borrowing Kierkegaard's irrational concept here from the philosophy of religion. Such an account, therefore, does not deal with how discovery or innovation in scientific thought comes into being, but only with the process of how such discoveries come to be accepted, how they come to be believed after they have been introduced.[35]

Even if we grant for the sake of the argument Wartofsky's claim that the emphasis of Kuhn and Popper was mostly on how new theories come to be

accepted rather than on how they were arrived at in the first place, still Wartofsky's characterization glides over certain useful things that Kuhn says about the act of creation. Kuhn states, for example, that a new hypothesis or theory comes into being as a result of perceiving an old situation in a new way (e.g. perceiving a swinging stone as a pendulum or combustion as a case of something being taken from the air rather than something being added to the air). That such novel perceptions can ultimately give rise to new theories, such as Lavoisier's chemistry, is undeniable. Some have construed this initial flash of genius as perceptual; others, as judgmental. But it could be both. Perceptions involve judgments as to the "whatness" of the "thatness" in the perceptual field of vision. That it is a case of judgment is indicated by the fact that it could be wrong, a misperception. Whether it is a useful or a creative perception can be ascertained only during periods of normal science when such hunches are pursued and developed further or theoretically debugged. If all seeing is interpreting and if there is no neutral observation-language as Einstein, Hanson, and Kuhn have argued, then it would seem to follow that judgments must enter in the very beginning of the creative act.

I find also implicit in Kuhn's model of scientific development, the admission of an interval of pursuit. There are two good reasons which constitute grounds for pursuit: (1) the new paradigm must resolve the anomaly that could not be resolved under the old paradigm; (2) the new paradigm must preserve most of the problem-solving capabilities of the earlier paradigm.[36] Furthermore, Kuhn's model allows us to see better than the Einstein model that the catalyst to scientific innovation is the anomaly – the incongruous observation. In a sense the incongruities between theories and experience ultimately give rise to anomalies. It seems to me that Einstein's model does not stress enough what aspect of experience gives rise to creative leaps. Kuhn does say that anomalies provide scientists with the irritant which gives rise to the jewel. Kuhn does not say, however, how the scientist must proceed to dispel the anomaly. In all fairness it should be said that neither does Marx Wartofsky. Wartofsky does say that reasoning or judgments are involved in creativity and that one must look at actual scientific practice if one is ever to understand the creative process. I agree with Wartofsky's position though he is not the first to have said it. Herbert Fox earlier attempted to go further on this point. He states in an article on creativity in science:

> To me, the creative process so called is the thinking process directed generally toward a specific goal, the solution of a problem and culminates in a synthesis of ideas which solve or advance the solution of the problem. For as long as the mechanism and elements of thinking escape our analysis and understanding so long shall we remain in ignorance of the creative process . . . the creative process is neither more nor less than productive

thinking . . .. Thinking need not be productive, the creative process must be.[37]

Fox rightly quotes Polya, who was one of the first to have made the point that creativity or discovery involves "plausible reasoning." Polya says "anything new that we learn about the world involves plausible reasoning."[38]

The problem with all of the above suggestions is that judgments or plausible reasoning in order to lead to some concrete conclusion must utilize concepts, but most revolutionary discoveries presuppose that the concept is invented. Ofter one cannot adequately characterize some novel phenomena unless one invents a new category. Subsumption under the category constitutes an explanation and involes judgments. It behooves us to look more closely at the major types of discoveries in science in order to explore the interconnections between discoveries and creativity in science and literature.

5. Types of discoveries and their relation to creativity

One might distinguish three basic kinds[39] of discoveries: (D_1) Accidental unplanned discoveries can arise as a result of the explanation of anomalies, as in the case of $\times$-rays, oxygen, and the positron. The development of novel categories and theories which can remove the anomalous observation completes the process of the first kind of discovery. Lavoisier's textbook *Chemistry* affords a good illustration of such a theoretical invention, for it explained the observed gain in the weight of sulpher. (D_2) In the second kind of discovery the thought comes first, whether we call it a theory, a law, or a model. Such a "thought" requires at times herculean efforts to produce, but it is the confirmation of novel predictions that is the focus. When a novel prediction is confirmed by observation a major discovery usually results and the theory receives the strongest empirical confirmation. When confirming observations are made of phenomena that were known prior to the creation of the theory, the theory is also supported but to a lesser degree. An excellent illustration of the second kind is providedly the discovery, in 1919, that light is bent when it passes near large bodies, to the degree that Einstein's general theory of relativity predicted. In the first kind of discovery belief or commitment plays merely a backdrop role against which something appears anomalous. In the second kind belief in the model or theory is crucial, for if the commitment is missing there will be little reason for pursuing the testing of the novel predictions.

The discovery of the positron could have been an example of this second type of discovery were it not for the fact that scientists did not believe the seemingly wild computations and theoretical postulates of Dirac, such as negative energy,

negative mass, and infinite charge. When enough belief or commitment is present for pursuit, new discoveries are often the result. My second example comes from chemistry. On the basis of a law and his table of elements Mendelyeev was able to predict accurately in 1869 the existence of such elements as gallium, scandium, and germanium. When Mendelyeev proposed his revolutionary system of classification it appeared strange and counter-intuitive to many chemists. Some suggested sarcastically that Mendelyeev give up his system and classify elements alphabetically. But he did not abandon his system. Here is an excellent illustration of how considerations of symmetry can lead to fruitful discoveries. Both theoretical and experimental creativity is required in this second type of discovery.

The requirement of both theoretical and experimental creativity is particularly well illustrated in the search for tachyons, the super-luminal particles. In 1962 three physicists, Bilaniuk,[40] Deshpande, and Sudarshan finally succeeded in publishing a paper in which they showed that the existence of super-luminal particles with imaginery mass does not contradict any of the postulates of Einstein's theory. There was resistance to such a particle because Einstein said that nothing travels faster than light. Great experimental ingenuity and creativity have gone into designing experiments to slow down and observe such particles at such laboratories as the Nobel Institute (Stockholm), Princeton University, Columbia University, Brookhaven National Laboratory, and others. The search for such particles will stop only if a law making their existence impossible is discovered or if the scientists run out of money. As Bilaniuk put it in a recent article, "absences without excuses are not tolerated in contemporary physics."[41]

(D_3) Laws or theories which unify apparently different phenomena, domains, classes, or fields constitute the third kind of discovery. When Galileo and Newton discovered laws of motion which for the first time unified terrestrial and celestial physics they found one of the greatest unifying laws in the history of mankind. For over a thousand years Aristotle's system had prevailed, with two systems of physics: celestial physics studies circular motions and terrestrial physics studied natural or up and down motions and violent or projectile motions.

It is possible that the third type of discovery is reducible to the second type. Both types of discovery involve the creation of theories or laws which are new, which unify apparently disparate phenomena. It is not certain, however, whether both types generate novel predictions, the defining mark of D_2.

Many observers of creativity have noted that creativity is a matter of degree. Some low level of creativity is probably a daily phenomenon with some people, maybe even most people. Hearing someone make an apropos comment in response to a situation is not unusual. Some people more so than others have a knack for saying apt things or for making apt puns. They naturally are more

creative than those who rarely make appropriate observations.

Such instances of creativity are dwarfed by the creativity required in the making of any of the three types of discovery. My hunch is that the first type of discovery probably requires the least measure of creativity because there is an accidental aspect to that type of discovery. Reasoning, memory, and a good data base are necessary, but ultimately what triggers the reasoning is the unexpected, the unexplained event. Think of the case of the discovery of x-rays. The continual exposure of photographic plates in Roentgen's laboratory led him to search for the cause. It was a matter of eliminating some possible sources and finally zeroing in on the cathode-ray tube in his laboratory.[42] The reasoning required was certainly not as complex as the reasoning that went into the development of Einstein's general theory of relativity.

We have so far determined that Einstein incorporates creativity as an integral part of his philosophy. We have furthermore discussed briefly the major types of discovery and have aligned discovery closely with creativity primarily because both aim at novelty under specified constraints.

6. Heuristics for scientific discoveries

Two kinds of questions come to mind concerning discovery and Einstein's epistemological model: (1) Is it possible to go beyond Einstein's suggestion that scientific theories or laws are arrived at by imaginative leaps? Or, to put the question another way, can there be a method or even a heuristic which could be used to speed up the rather mysterious and enigmatic process of discovery? (2) Can such discoveries or creative processes in science be explicated on a rational basis? Are they arrived at as a result of a reasoning process? Similar questions can be formulated about the process of creation in literature, as I shall discuss below.

a. *Bisociative thinking*

It has become commonplace to observe that creativity in both science and literature involves bisociative or Janusian thinking. Koestler defines bisociative thinking as follows:

> I have coined the term "bisociation" in order to make a distinction between the routine skills of thinking on a single "plane," as it were and the creative act, which as I shall try to show always operates on more than one plane! The former may be called single-minded, the latter a double-minded transitory state of unstable equilibrium where the balance of both emotion and thought is disturbed.[43]

Koestler later refers to bisociation as "the sudden interlocking of two previously unrelated skills, or matrices, of thought."[44] That such interlocking often occurs in discoveries in science as well as in the creation of metaphors in literature cannot be denied. The unification of celestial and terrestrial physics by Galileo and Newton serves as the paradigm illustration of such a unification. Our question, however, is, does bisociative thinking, if we can call it thinking, answer either of the following two questions; i.e., can it serve as a method and/or does it explicate creativity as a rational process? I think that it answers neither question adequately. It is not a very fruitful method or heuristic for making discoveries in science, for one cannot randomly go around juxtaposing different categories, fields, or matrices of thought with the hope of making a significant theoretical breakthrough. The process would be very time-consuming.[45] But even more importantly, how would one decide whether something significant comes out as a result of such a juxtaposition? Above all what Koestler does not seem to notice is the fact that, particularly in science, novel original hypotheses or theories involve novel ideas or interesting proposals for interrelationships among various parameters, as in the case of F = ma. Juxtaposition without unifying ideas produces unrelated diversity, not a new unity.

We can already see why bisociative or Janusian thinking won't help make the creative process in discoveries understandable either. To see that two apparently unconnected fields or categories have been unified by subsumption under a more general theory or concept, as in the case of Maxwell's equations, is not to explain that the theory or concept has been arrived at as a result of a reasonable set of steps. For help along these lines the historian of science has to enter the biographical history of the scientist during the gestation period. Detailed historical reconstructions of the problem field as well as a study of the ideational exposures that the scientist underwent will help, but neither may be sufficient as an explanation of the creative process in the particular case.

b. *The role of models and analogies as heuristics in scientific creativity*

A more fruitful approach comes from the use of analogies.[46] There are two types of analogies that can serve as a heuristic for making discoveries in science. Formal analogies can be used to provide ready solutions from one field to another.[47] Thus the laws of hydrodynamics which govern the flow of water through a pipe have supplied scientists with a useful analogy for the formation of laws governing the flow of traffic.

Kenneth Arrow[48] provides another illustration of how the formal analogies to the law of gravitation supply scientists with an empirical hypothesis as to the flow of traffic and information between two cities. Scientists have been

recently testing the hypothesis that the interaction between two cities is inversely proportional to the distance between them.

Another heuristic for hypothesis-formation comes from the use of neutral analogy. The Bohr model of the atom can serve as an illustration. In the solar system, here called the parent model (M_2), the spin of a planet on its axis constitued a neutral analogy for the Bohr model (M_1), because originally the question whether electrons have spin did not arise. Revolutions of planets around a fixed center provide an example of a positive analogy because electrons are also said to be revolving around a fixed center, here called the nucleus. The tremendous differences between the size of the planets and of the electrons, and the fact that planets reflect light and electrons do not provide instances of the negative analogies between the two models. Because of the many positive analogies or similarities it was reasonable to think that the neutral analogies could be converted to positive analogies.[49] If only some scientist would have explored this neutral analogy between M_2 and M_1 and formulated the electron spin hypothesis, the Zeeman effect could possibly have been explained fifteen years earlier.

Enough has been said to establish a beachhead for philosophy in the area of creativity in science. We have seen how models and analogical reasoning can be heuristic in scientific discovery. Other methods worthy of mention are the methods of modeling, computer simulation, curve fitting, and enumerative induction. The more difficult task of establishing philosophical issues in literary creativity still remains. Discussions centering on the issue of criteria of a good literary work have long been a well-recognized province of philosophy, i.e., aesthetics. Questions of creativity, however, have often been relegated to a branch of psychology.[50] The task before us then is to explore philosophical issues in literary creativity and to show that there are significant parallels between scientific and literary creativity and achievements.

7. Metaphors – Their nature and their role

The bridge between creativity in science and literature lies in the use of models, analogies, and metaphors. Part of the reason why the sciences and humanities have for so long been seen as separated by an unbridgeable gulf is that models, analogies, and metaphors have not received adequate attention in the past. In a literature search I conducted for the preparation of this paper, the Social Citation Index (SSCI) data base confirmed a lack of attention to the cross between metaphor or analogy and creativity. There were 294 entries under metaphor or analogy and 2115 entries under creativity or creative process or creative product or innovation or discovery. But when the first and second categories were crossed there were only four entries, of which only two were relevant to my topic.

That good metaphors are among the central achievements of poetry and other genres of literature needs no argument. In order, however, to gain an insight into the process of creating good metaphors and their relation to science we should pause briefly to consider the controversial topic of the nature of metaphor.

a. *A brief historical excursion*

It was Kant and later Nietzsche who glorified metaphor and recognized it for what it is. Kant recognized that metaphors enable man to engage in thought when there are no ready literal terms or concepts available for man's use.[51] Nietzsche went even further. He saw metaphors as pervasive in all human thought and as crucial to our knowledge of the world. Metaphor is a process in terms of which man confronts the world: "A nerve stimulus, first transformed in a percept! First metaphor! The percept again copied into a sound! Second metaphor!"[52] Nietzsche becomes even bolder when he claims that originally all experience of reality is metaphorical. He states:

> What therefore is truth? A mobile army of metaphors, metonymies, anthropomorphisms: in short a sum of human relations which become poetically and rhetorically intensified, metamorphosed, adorned and after long usage seem to a nation fixed, canonic and binding; truths are illusions of which one has forgotten that they are illusions; worn-out metaphors which have become powerless to affect the senses . . ..[53]

These very suggestive ideas of Nietzsche were mostly ignored in Anglo-American philosophy. But there is a new revival of the study of metaphor as well as of Nietzsche's philosophy.

In the twentieth century much that has been claimed by poets, writers, and even philosophers about the nature of poetry and the concept metaphor has often turned out to be more puzzling than illuminating. Take for example the statement by the philosopher-poet, Wallace Stevens. He wrote that "reality is the central reference for poetry" and thus in order to understand poetry one has to "examine one of the significant components of the structure of reality – that is to say, the resemblance between things."[54] The belief that man has access to reality independent of language and of theoretical frameworks was a cronerstone of the thinking not only of some poets like Wallace Stevens but also of many philosophers of the forties and fifties. In the sixties and seventies philosophers and historians of science questioned that assumption. As a result, Stevens' claim appears naive to us today. Stevens' claim would be more plausible were we to interpret him as speaking of experience, of reality as

experienced. Then the poet rightly speaks of reality structured, that is, of reality as interpreted and filtered by his concepts, desires, wishes, etc.

When Stevens speaks of metaphor he does say things that are much more illuminating. He breaks away from the classical Aristotelian conception of metaphor as based on previously existing resemblances or similarities[55] and expands the idea of metaphors to include created resemblances. Stevens states:

> In metaphor (and this word is used as a symbol for the single aspect of poetry with which we are now concerned – that is to say, the *creation of resemblance by the imagination*, even though metamorphosis might be a better word) – in metaphor, the resemblance may be, first, between two or more parts of reality; second, between something real and something imagined or, what is the same thing, between something imagined and something real as, for example, between music and whatever may be evoked by it; and, third, between two imagined things as when we say that God is good, since the statement involves a resemblance between two concepts, a concept of God and a concept of goodness.[56]

But Stevens still depends heavily on the concept of metaphor as based on resemblances even if they created rather than found. That resemblances are the basis of many metaphors is obvious. Consider, for example, the poem of H.D. Doolittle where the resemblances between waves and pines are highlighted:

> Whirl up, sea –
> Whirl your pointed pines,
> Splash your great pines
> On our rocks.[57]

What has gone unnoticed until very recently is that there are metaphors which are not based on similarities.

b. *Metaphors as experiential gestalts*

A more fruitful approach to metaphor has been developed recently, under which a new metaphor is best understood as a type of perspectival seeing. The metaphor enables us to see old objects, experiences, in a new way. Psychologists describe similar experiences as gestalt switches of the duck-rabbit type. This suggestion was developed originally by Hester,[58] following a suggestion of Wittgenstein, and more recently by Lakoff and Johnson.[59] They claim that actions, events, and objects are best understood in terms of "experiential gestalts," structured meaningful wholes within experience. Each

gestalt consists of various recurring subpatterns of the whole structure.

In the case of "war" as in many other gestalts there are such aspects as participants, adversaries, stages, causation, and purpose. Johnson gives a very detailed analysis of the metaphor "argument is war" in terms of such gestalts. He shows how the two gestalts of argument and war are fused into one. After such a fusion we can use the language of war to speak of other aspects of arguments: "He attacked the weak points in my argument," or "I defended my position and destroyed his." In commenting on such examples Johnson summarizes the central aspect of this analysis of metaphors: "The metaphorical meaning is based upon the projection of one common gestalt structure (e.g., war) onto another (e.g., arguments). What emerges is a new gestalt that restructures aspects of our experience, thought, and language."[60]

What is fascinating for philosophical purposes is that metaphors on this analysis could be processed rationally. That is, one could show by what series of steps one goes from the old category to the new category created by the metaphor. Whether this interpretation of metaphor proves capable of analyzing all types of metaphors remains to be seen. What is interesting for our purposes is the usefulness of such an analysis of metaphor for the analysis of poetic creativity and for seeing the close parallel between poetic and scientific creativity.[61]

c. *Metaphors and creativity in literature and science*

Both scientists and poets often describe achievements in terms of accidental discoveries. C.S. Lewis, in describing the creation of metaphors, states: "One of the ways we invent a new metaphor is by finding it, as unexpectedly as we might find it in the pages of a book, and whatever is true of the new metaphors that we find in books will also be true of those that we reach by a kind of lucky chance, or inspiration."[62]

What the poet or the scientist finds by luck or accident is a new aspect of things, of events and experiences. These novel aspects previously went unnoticed and it is the poet who by the metaphor highlights or even creates such novel aspects. True, in the case of accidental discoveries in science there was in the beginning the perceived anomaly, the strange experimental result which could not be explained within the context of the old theories. One could say that in the case of this type of accidental discovery there is the puzzle or problem (e.g., phlogiston theory predicts a loss in weight during combustion while the experimental results show a gain in weight). But in the case of the discovery of metaphors it is not clear that a problem exists. For the most part there is no analogous anomaly for the poet. There is the problem of creating a good poem or a novel, but this is not a fruitful analogue. I suspect, however,

there are times when the poet has the perception of some novel aspect before he has the metaphor, and the metaphor constitutes the linguistic characterization of his perception. Since there are no ready-made terms in the language that fit the perception or experience, the poet creates the metaphor for such purposes.[63] Ina Loewenberg puts the point in the following way: the "Metaphor increases what we can significantly say that is novel with the vocabulary we have. In the sense in which an extension of knowledge always involves the assimilation of new insights to old, metaphor extends our knowledge."[64]

d. *Gestalt-switches in scientific and literary creativity*

Both the poet's and scientist's novel experience have been characterized as a new gestalt, a seeing of old objects and experiences, in a new way. Kuhn[65] has suggested that new gestalt switches can give rise to revolutionary models and theories in science. To support his claim he cited such examples as seeing the sun as stationary and the earth as moving or seeing the swinging stone as a pendulum. For the suggestion that some theories originate in a gestalt switch Kuhn was viciously attacked. But if gestalt switches occur as well in the case of good metaphors and if metaphors can be processed in an illuminating way as specifiable shifts in the gestalts associated with this or that concept, then Kuhn's suggestion need not be looked at as irrational or obscurantist. True, the gestalt switch is not the theory, but at times it can give rise to the development of a new theory.

I do not want to give the impression that the experience of a gestalt switch precedes every novel metaphor or revolutionary theory. But I hope no one will deny that examples of such switches can be found in the history of both science and literature.

The same difficulties that scientists and others have with the proper interpretation of certain types of strange phenomena can be found even more often among students of these fields. For students novelty is relative to their state of knowledge rather than to the state of knowledge of the profession. But the difficulties are the same. Take the following passage quoted by Hanson which described a common experience of novices in science:

> An object is frequently not seen *from not knowing how to see it* rather than from any defect in the organ of vision . . .. (Herschel said) "I will prepare the apparatus, and put you in such a position that (Fraunhofer's dark lines) shall be visible and yet you shall look for them and not find them: after which, while you remain in the same position. I will instruct you *how to see them*, and you shall see them, and not merely wonder you did not see them

> before, but you shall find it impossible to look at the spectrum without seeing them. (Babbage, *The Decline of Science in England*; R. Clay, London, 1830).[66]

Even though Herschel does not use the term gestalt switch, he certainly has the gestalt switch experience in mind in the above passage. What is revealing for our purposes about Herschel's description of gestalts is that directions can be given for helping to see these patterns. The gestalt experience is therefore not irrational. Newton-Smith points out that, whereas in the duck-rabbit gestalt switch one can go back and forth, alternatingly seeing the duck and rabbit, there is no back-sliding in science. "For the innovative scientist it is much more likely that the new 'set' once grasped is fixed."[67]

In spite of this disanalogy I do feel that the gestalt switch is an appropriate characterization of the initial experience of some innovative scientists. Whether the term gestalt switch is also appropriate as a characterization of theory change or even more global changes in world-view is another matter. We have to interpret gestalt switches in this larger theoretical context metaphorically. There are some dramatic differences in the beliefs of the scientist before and after a paradigm-theory change, but such change normally undergoes a long preparatory stage of weighing reasons and looking at the data.

Something like the characterization by Herschel also goes on in the case of metaphors in poetry. When a reader does not understand a metaphor he can be directed to notice aspects of connotative meaning of the terms of the metaphor and often this will suffice for him to understand the metaphor. Much depends on the background knowledge and experience of the reader. At times one needs detailed biographical data about the poet's experience to help unravel a very personal metaphor. Such personal data are at times necessary to unravel some of Wallace Stevens' poetry.

8. A heuristic for literary creativity

a. *Role of models in literary criticism*

Thus far I have talked about literary works and the metaphors contained therein as if they could be understood in isolation, without reference to the rest of the writer's corpus. In spite of the fact that some poems and metaphors are amenable to that kind of atomistic interpretation, the formalists and the phenomenlogists have been unsuccessful in providing the full significance of some metaphors as well as of some larger literary works.

A very fruitful approach to the study of literature has come from the structuralists,[68] who subscribe to the principle that nothing has meaning in

itself. When this principle is applied to literature one gets the view that in order to understand a poem or novel more deeply one has to uncover the model of the world implicit in the corpus of writings of the particular writer. Poems and novels can be read on many levels. Often the deeper significance of the work will be hidden unless one is able to reconstruct the model of the world implicit in the works. This will be particularly true of such works as Swift's *Gulliver's Travels*, Lewis Carroll's *Alice in Wonderland*, Kafka's *The Trial*, and Zinoviev's *The Yawning Heights*. Each of these works may be read on various levels. But unless we reconstruct the model implicit in the work together with the system of codes we will not decipher the deeper meaning of these works. George G. Grabowicz,[69] of Harvard, has recently provided an excellent example of such a deeper reading of the Ukrainian bard Shevchenko.

The case of Shevchenko is interesting because for almost one hundred years his poetry has been read by the masses on a very superficial level as handy bits of sentiment. Grabowicz uncovers the model that supplies the code for interpreting Shevchenko's poetry on a deeper level. Without Shevchenko's model of Ukraine in the background many of his poems would be read as they have been read on the literal level. The Zaporozhian Kozaks would not be symbols of death but simply the brave warriors that defended Ukraine against such enemies as the Turks. Tartars, Poles, and Russians. Just as in science models serve the purposes of interpretation of theoretical terms, so in literature we see that models have a parallel function. They supply the reader with an interpretation of the symbolic nature of various objects referred to in a literary work.

b. *Important similarities between the use of models in literature and science*

An interesting question raised by the structuralists' discussion of myth and models in literature is whether such modes of thinking are similar to those utilized in science or are radically different. Some structuralist literary critics like Grabowicz argue that "Mythical thought is the opposite of rational, analytical, historical thought, which takes a discrete body of data, that is, events, and by analysis and deduction sees a pattern or meaning or structure in them."[70]

In contrast, mythical thought "moves from structures to events: one starts with a structure, which in the case of Shevchenko is a sense, an understanding, a deeply felt 'truth' of, say, the nature of Ukrainian existence, and from this one creates or adapts various events or figures, for example an archetypal Cossack, or a purported historical event."[71]

This contrast between mythical and literary thinking on the one hand and scientific, rational thinking on the other has been seriously challenged in the last twenty years. The challenge has taken two forms. Philosophers like Paul

Feyerabend in his work *Against Method*[72] have argued that science proceeds counter-inductively, that "anything goes" is a better maxim for science than any of the other identifiable methodologies. Furthermore, since scientific, mythological, and literary thinking does not follow a method, it therefore contains an irrational element. The other group claims that mythological and literary thinking resemble in certain essential respects scientific thinking if only because the theories and models in the former are creations or inventions of the mind. Conversely, models and theories in science also are idealizations and contain a mythical component. They also highlight only certain features of the world to the exclusion of others. For example, in the Newtonian theory consider how even large heavenly bodies are construed for purposes of calculation as point masses, or how force is computed by abstracting from all other properties of objects except mass and acceleration. The social sciences are no different here from the natural sciences. Theories and their corresponding models highlight only certain features to the exclusion of others. Consider for example how in Marx's theory only the economic forces are taken as determinants of the superstructure of man's ideas, values, moral codes, etc., or how Freudian psychoanalytic theory takes the sexual drives as determinant of man's behavior.

None of these features appear to me to make science irrational; nor have they made it irrational for the majority of the top scientists including, as I have shown. Einstein. Furthermore, there is something counterintuitive in the claim that poetry is irrational. It is hard to reconcile such a claim with the hard cerebral reasoning that often goes into deciphering a metaphor or a poem. I therefore am prepared to defend the second interpretation of both science and literature, which claims that the two resemble each other in certain essential respects.

My quarrel then with the structuralists is not with their fruitful approach to the interpretation of literary works but with their characterization of the contrast between mythical and scientific thinking. I do not want to say that there is no difference between these two kinds of thinking but that the difference has to be put another way. Part of the difference between scientific and literary creativity lies in the different values and goals implicit during certain historical periods in each activity. Whereas predictive accuracy and control of nature are foremost values essential to any good modern scientific model or theory, certain other values dominate in good literary works within certain traditions. But this is a topic that merits separate consideration.[73]

c. *A conjecture*

More central to the question of creativity in science is to see how scientific

models and analogical reasoning based on the models can serve to generate fruitful hypotheses and the further development of the theory they represent. I want now to suggest that models of the world serve as a heuristic for the literary writer or poet as well. Such models of man, of nature, of the world can provide a stimulus for the creative outpouring of the poet, novelist, or dramatist. Without such models the author is totally cut off from a perspective or an interpretation. He is in short confronted with an infinity of possibilities and it is therefore natural to wonder how one could make sense of the creative process in the face of such unlimited possibilities. The greatest writers had such models of the world to guide their creative energies, but unless the writer kept a diary or explicitly directed our attention in the work it is often difficult to get at such models. In the case of Joseph Conrad the matter is easier, for in the preface of his novel *Nostromo* he describes how he came upon the basic model of man that guided his writing of the novel. He describes how he once heard a story about an "unmitigated rascal" who had stolen a large quantity of silver. Conrad says, "I did not see anything at first in the mere story." Then: "It dawned upon me that the purloiner of the treasure need not necessarily be a confirmed rogue, that he could even be a man of character." This idea that a man or a country could be both good and evil Conrad developed in his novel. As he says, "It was only then that I had the first vision of a twilight country . . . with . . . its high, shadowy sierra and its misty campo for mute witnesses of events flowing from the passions of men short-sighted in good and evil. Such are in very truth the obscure origins of *Nostromo* – the book. From that moment, I suppose, it had to be."[74]

Models also function in other ways in poetic or literary creativity. The form of a poem or other literary work can provide a strong direction for a writer's creative energies. In such cases an element of imitation plays the central role. The poet is consciously trying to duplicate the success achieved by a particular stanza structure in another poem by another poet. Here is what Robert Lowell says about the creative process of the formation of his poem "Skunk Hour":

> The dedication is to Elizabeth Bishop, because re-reading her suggested a way of breaking through the shell of my old manner. Her rhythms, idiom, images, and stanza structure seemed to belong to a later century. "Skunk Hour" is modeled on Miss Bishop's "The Armadillo," a much better poem and one I had heard her read and had later carried around with me. Both "Skunk Hour" and "The Armadillo" use short line stanzas, start with drifting descriptions and end with a single animal."[75]

Such imitations of a work do not constitute an isolated case either in literature or in science. Kuhn has described a similar role for Newton's *Principia* or Lavoisier's *Chemistry*. Achievements such as these functioned for many years

as heuristics for further research. I have elsewhere called them paragons of science on the analogy with moral paragons of virtue.[76]

In literature the writer does not bring the products of literary creativity out of nothing. Creation in literature is closer to the Platonic conception of creation found in the *Timaeus* rather than the creation *ex nihilo* found in the Bible. In the *Timaeus* Plato describes how the Demiurge creates new forms out of chaos but not out of nothing. Similarly, writers create new poems, novels, and plays out of bits and pieces they find in their environment, some story in the newspaper, part of some place they recently visited.[77] All such items are put together in a new way to create some mood, express some message, create some metaphor. Literary creations like scientific creations are further guided by a set of constraints. Among literary constraints are such things as (a) a vague something the writer wants to say, (b) semantic and syntactic conventions, (c) artistic conventions.[78]

NOTES

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1 Marx Wartofsky put it recently in terms of a paradox in which the more knowledge acquisition is reduced to a method the less there is room for discussions of creativity. See Marx W. Wartofsky, "Judgment, Creativity and Discovery" in *Scientific Discovery: Case Studies*, ed. Thomas Nickles (Dordrecht and Boston: D. Reidel, 1980), p. 8.

2 The most dramatic exception can be found in René Descartes' clock metaphor. For discussion of the clock metaphor see Larry Laudan, *Science and Hypothesis* (Dordrecht: D. Reidel, 1981), pp. 27–58. For the original text see René Descartes, *Oeuvres* ed. Charles Adam and Paul Tannery, 12 vols. (Paris: J. Vrin, 1956), 9:322.

3 For Aristotle's account of scientific knowledge see *Nicomachean Ethics*, 6.3: "Scientific knowledge is then, a state of capacity to demonstrate . . .. Scientific knowledge is of necessity. Therefore it is eternal." For Aristotle, scientific knowledge together with intuition (by means of which man arrives at first principles) constitutes the intellectual virtue of theoretical wisdom (*sophia*).

4 Newton states, ". . . whatever is not deduced from the phenomena is to be called an hypothesis; and hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy" (General Scholium, *Principia*, 3). For a useful discussion of Newton's claim about deduction, see Errol Harris, *Hypothesis and Perception* (London: George Allen and Unwin, 1970), pp. 102–109. Harris (esp. chap. 6, "Deduction

from Phenomena'' trans. and rev. Andrew Motte [New York: Daniel Adee, 1848] pp. 506–07) proposes an interesting interpretation of Newton's principle based on the assumption that nature comes already interpreted and then proceeds to show how such ''derivations'' are possible. Mary Hesse shows what principles must be accepted if Newton's claim that the law of gravity can be derived from nature is to be plausible (*The Structure of Scientific Inference* [Berkeley: University of California Press, 1974] pp. 201–08).

In both Harris' and Hesse's discussions of Newton's claim the phenomena are not uninterpreted, but are on the contrary highly theory-laden. Naturally, if enough principles are assumed then derivation is possible. But is this really derivation from nature?

5 Carl G. Hempel, *Philosophy of Natural Science* (Englewood Cliffs, NJ: Prentice Hall, 1966), pp. 11–18. For a discussion of the problems with inductivism see also my ''Scientific Revolutions: A Philosophical Critique of the Theories of Science of Thomas Kuhn and Paul Feyerabend,'' Diss., University of Pennsylvania 1969, pp. 96–101.

6 For computer-simulated laws se Gary F. Bradshaw, Patrick W. Langley, Herbert A. Simon ''Studying Scientific Discovery by Computer Simulation,'' *Science*, 2 Dec 1983. They have developed computer programs named Bacon 1–4 that simulated data-driven inductions of such laws as Black's law (p. 973), Kepler's third law, and others.

7 See Hesse, *The Structure of Scientific Inference*. There are many features of Hesse's system which are commendable, not the least of which are: she recognized the analogical extensions of the meaning of terms from the old system to the new (''new situations to be described by complex combinations of old predicates,'' p. 221); she allows for the introduction of novel concepts in science; she recognizes a network model of theories; she stresses the importance of models in the growth of science; and she recognizes the underdetermination of theories by the data.

8 Locke's animosity towards figurative language is captured in the following passage:

> But yet if we could speak of things as they are, we must allow that all the art of rhetoric, besides order and clearness; all the artificial and figurative application of words eloquence hath invented, are for nothing else but to insinuate wrong ideas, move the passions, and thereby mislead the judgment; and so indeed are perfect cheats. *Essay Concerning Human Understanding*. 3.10.34; quoted and discussed in *Philosophical Perspectives on Metaphor*, ed. Mark Johnson (Minneapolis: University of Minnesota Press, 1981), pp. 12–13.

9 For a fresh and inciteful account of Reichenbach's distinction between the context of discovery and the context of justification, see Martin Curd, ''The Logic of Discovery: an Analysis of Three Approaches,'' in *Scientific Discovery: Case Studies*, ed. Nickles, pp. 201–21; also, a good summary of the results is provided in Thomas Nickles, ''Introductory Essay: Scientific Discovery and the Future of Philosophy of Science,'' in *Scientific Discovery, Logic, and Rationality*, ed. Thomas Nickles (Dordrecht and Boston: D. Reidel, 1980), pp. 8–10. Both Curd and Nickles have shown that Reichenbach's distinction has been misconstrued. Reichenbach intended the distinction between the context of discovery and the context of justification to be not temporal, but only logical. Thus it is compatible with Reichenbach's views to see justification as taking place throughout the process of discovery.

10 See V. I. Lenin, *Materialism and Empirio-Criticism*, 2nd. ed. New York: International Publishers, 1927). Lenin says, ''At present let us note that Mach explicitly states here that things or bodies are complexes of sensations, and that he quite clearly sets up his own philosophical point of view against the opposite theory which holds that sensations are 'symbols' of things (it would be more correct to say images or reflections of things). The latter theory is *philosophical materialism*'' (p. 33). Or again in his account of matter Lenin states, ''Matter is a philosophical category designating the objective reality which is given to man by his sensations, and which is copied, photographed and reflected by our sensations, while existing independently of them'' (p. 128). For an insightful critique of Lenin's views, see David-Hillel Ruben, *Marxism and Materialism: A Study in Marxist Theory of Knowledge* (Atlantic Highlands, NJ: Humanities Press, 1977), pp. 165–199.

11 My research on Einstein's philosophy of science was in part supported by a 1978 NEH Summer Seminar Grant. For a fuller treatment of Einstein's philosophy, see my ''Einstein's Philosophy

and Its Influence on Basic Concepts in the Natural Sciences" (in Ukrainian), *Ukranian Engineering News* 33 (1982): 1–8; also, my article "Einstein and the Problem of Theory Choice," presented at the University of Maryland, August 7, 1980.

12 For the complete correspondence see Albert Einstein, *Lettres à Maurice Solovine* (Paris: Gauthier-Villars, 1956). The letter is reprinted in *Einstein: A Centenary Volume*, ed. A.P. French (Cambridge MA: Harvard University Press, 1979), pp. 270–273. A useful discussion of the letter can be found in Gerald Holton, "Constructing a Theory: Einstein's Model," *The American Scholar* 48 (1979): 309–40.

13 Einstein, "Principles of Theoretical Physics," in *Ideas and Opinions*, trans. and rev. Sonja Bargmann (New York: Crown, 1954), p. 221. These essays are based on Einstein's *Mein Weltbild* (1934), together with later pieces.

14 Einstein, "Principles of Research," in *Ideas and Opinions*, p. 226.

15 Einstein: *A Centenary Volume*, ed. French, p. 272.

16 Mary Hesse, *Models and Analogies in Science* (Notre Dame, Indiana: University of Notre Dame Press, 1966), particularly "The Explanatory Function of Metaphor," pp. 157–177.

17 Albert Einstein, "Authobiographical Notes," in *Albert Einstein: Philosopher-Scientist*, ed. Paul Arthur Schilpp (La Salle, IL: Open Court, 1970), p. 13.

18 Einstein, "On the Method of Theoretical Physics," in *Essays in Science*, pp. 15–16.

19 These extensions of Einstein's model were originally proposed by Holton in "Constructing a Theory."

20 Arthur Fine in an otherwise interesting paper called "Einstein's Realism" which appeared in *Science and Reality*: *Recent Work in the Philosophy of Science. Essays in Honor of Ernan McMullin*, James T. Cushing, C.F. Delaney, Gary M. Gutting editors (pp. 106–133) overstates Einstein's empiricism. Fine does not seem to appreciate the limitations of empirically adequate theories and the need to supplement empirical adequacy with the internal perfections of a theory and other themata to help choose that theory which will be a realist theory. Fine says, for example, "Indeed it would not be too far off if we summarized Einstein's views this way: 'Science aims to give us theories which are empirically adequate; and acceptance of a theory involves as belief only that it is empirically adequate'." (p. 125) or when he quotes Einstein on the need for choosing simplest theories Fine states "Thus Einstein deflects questions of meaning and, just as we would expect, goes on to entheorize and to focus on empirical adequacy instead:" (p. 123).

21 Einstein, *The World As I See It*, trans. Alan Harris (London: The Bodley Head, 1939), pp. 139–40.

22. Max Black, *Models and Metaphors* (Ithaca, NY: Cornell University Press, 1966), pp. 25–47.

23 Larry Laudan, *Progress and Its Problems* (Berkeley: University of California Press, 1977), particularly pp. 11–45.

24 Holton, "Constructing a Theory," pp. 334–35.

25 Einstein, "Autobiographical Notes," p. 23 (my emphasis).

26 Holton, "Constructing a Theory," pp. 334–35.

27 Thomas Nickles, "Can Scientific Constraints Be Violated Rationally?" in *Scientific Discovery, Logic and Rationality*, ed. Nickles, pp. 285–317.

28 For a critical discussion of the above theses se my, "Scientific Revolutions"; see also Frederick Suppé's introduction to *The Structure of Scientific Theories*, ed. Frederick Suppé, 2nd ed. (Urbana: University of Illinois Press, 1977), pp. 125–217.

29 For a persuasive discussion of the implications of scientific revolutions, see Thomas Kuhn, *The Structure of Scientific Revolutions*, 2nd ed. (Chicago: University of Chicago Press, 1970).

30 Stephen Toulmin has a useful discussion of the role of alternative geometrics to the problem of conceptual change in *Human Understanding* (Princeton: Princeton University Press, 1972), p. 51.

31 Toulmin, *Human Understanding*, pp. 41–43; see also Abraham Edel and May Edel, *Anthropology and Ethics* (Springfield, IL: Thomas, 1959).

32 For a statement of this problem, see Einstein's forceful claims discussed in this paper. More recently Mary Hesse has discussed the underdetermination of theories in her Inaugural Adress to the Philosophy of Science Association Meeting, 1978.

33 For the most vehement attack on Western Philosophy construed as a form of mirroring, see

Richard Rorty's *Philosophy and the Mirror of Nature* (Princeton: Princeton University Press, 1979).

34 Kuhn, *The Structure of Scientific Revolutions*.

35 Marx Wartofsky, "Judgment, Creativity and Discovery," p. 4.

36 Most of Kuhn's critics have missed this point and have made Kuhn out to be an irrationalist. For a discussion of this and other points relating to the rationality issue, see my "Scientific Revolutions," particularly pp. 44–70, as well as my, "A Rational Reconstruction of Kuhn's Model of Rationality in Science," *Proceedings of the 16th World Congress of Philosophy* (in press).

37 H. Herbert Fox, "A Critique on Creativity in Science," in *Essays on Creativity in the Sciences*, ed. Myron A. Coler (New York: New York University Press, 1963), p. 133.

38 Gyorgy Polya, *Mathematics and Plausible Reasoning*, 2 vols. (Princeton: Princeton University Press, 1959).

39 For a useful discussion of types of discoveries see: Richard Blackwell's *Discovery in the Physical Sciences* (Notre Dame: University of Notre Dame press, 1969), chap. 11; my "Discoveries as Indices of Progress in Science," *Proceedings of the Fifth International Congress of Logic, Methology, and Philosophy of Science* (London, Ontario: 1975), pp. 73–74.

40 For a summary and discussion of the search for tachyons, see O.M. Bilaniuk and E.C.G. Sudarshan, "Particles Beyond the Light Barrier," *Physics Today* 22, no. 5 (1969): 43–51.

41 O.M. Bilaniuk and J.R. Boccio, "Les Particules Introuvables," *La Recherche* 4 (1973): 1037–47.

42 For a discussion of the discoveries of X-Rays by Roentgen, see Kuhn, *The Structure of Scientific Revolutions*, pp. 58–59.

43 Arthur Koestler, *The Act of Creation* (New York: Dell, 2964), p. 36. The term "Janusian thinking" can be found in the writings of Albert Rothenberg: "In Janusian thinking, two or more opposites or antitheses are conceived simultaneously, either as existing side by side, or as equally operative" ("Creative Contradictions," *Psychology Today*, June 1979, p. 55).

44 Koestler, *The Act of Creation*, p. 121.

45 Alfred Burger in his lecture "Creativity in Medicinal Chemistry and Biochemistry," which was presented at the "Creativity and Science Conference" in Honolulu March 23–24 1985, describes just such a systematic trial and error testing of all known compounds for possible medicinal effects for the treatment of certain diseases. Sometimes years of testing or "juxtaposition" was productive and sometimes not.

46. See for example, Pierre Duhem's forceful statement on the role of metaphors: "the history of physics shows us that the search for analogies between two distinct categories of phenomena has perhaps been the surest and most fruitful method of all the procedures put in play in the construction of physical theories" (*The Aim and Structure of Physical Theory*, trans. Philip P. Wiener [New York: Atheneum, 1962], p. 96).

47 For many early examples of such formal analogies and their role in the growth of such fields as Darwinian Evolutionary Theory, see the fascinating article written in 1918 by M.I. Tuhan-Baranovkyi, "The Influence of Ideas of Political Economy on the Natural Sciences and Philosophy," *Annals of the Ukrainian Academy of Arts and Sciences in the U.S.* 13 (1973–77): 190–209 (English translation). For a discussion and evaluation of Tuhan-Baranovkyi's article, see my "Some Reflections on the Relationship between Philosophy and Economics," *Annals of the Ukrainian Academy of Arts and Sciences in the U.S.* 13 (1973–1977): 217–237.

Lindley Darden has proposed the hypothesis "that interfield connections are better than analogies as a source of new ideas," because (1) the use of interfield connections produces a more plausible theory if the interfield connections have been empirically confirmed . . ." and (2) "using the interfield connections in the construction of a theory provides a unification of that theory with other fields of science at the outset" ("Theory Construction in Genetics," in *Scientific Discovery: Case Studies*, ed. Nickles, pp. 167–68). For detailed historical examples of analogical reasoning in hypothesis and theory formation, see also Darden's "Reasoning in Scientific Change: Charles Darwin, Hugo DeVries, and the Discovery of Segregation," *Studies in the History and Philosophy of Science* 2 (1976): 127–169, particularly pp. 143–47.

48 Kenneth Arrow, "Mathematical Models in the Social Sciences," in *Policy Sciences*, ed. D. Lerner and H.D. Lasswell (Stanford: Stanford University Press, 1965), p. 150.

In a sweeping generalization Max Born claims, "All great discoveries in experimental physics have been due to the intuition of men who made free use of models, which were for them not products of the imagination, but representatives of real things" ("Physical Reality," *Philosophical Quarterly* 3 [1953]:140). A more cautionary note is expressed by Bernard Barber: models may also "be a source of blindness" ("Resistance by Scientists to Scientific Discovery," *Science* 134 [1961]: 596–602.

49 Mary Hesse popularized the notion of positive, negative, and neutral analogies in her now classic book *Models and Analogies in Science*. The first to use these notions, however, was J.M. Keynes in *A Treatise on Probability* (London: Macmillan, 1921). For a very thorough treatment of models and analogies and for a critical discussion of both Keynes and Hesse, see A.I. Ujomov, *Logicheskii Osnovy Metoda Modelyrovannia* [Logical Basis of the Modeling Methods] (Moscow: MYSL, 1971), particularly the discussion of Hesse (pp. 158–60).

50 After this paper was written I received in the mail a copy of Larry Briskman's brilliant article in which he argues for a philosophical treatment of the problem of creativity and why the psychological approach is inadequate. See his "Creative Product and Creative Process in Science and Art" in D. Dutton and M. Krausz, eds. *The Concept of Creativity in Science and Art* pp. 129, 155, 1981, Martinus Nijhoff Publishers, The Hague/Boston/London. In general I find his article very congenial to my approach.

51 For a useful historical introduction and critique of the various theories of metaphor, see Johnson's Introductory Essay in *Philosophical Perspectives on Metaphor*, ed. Johnson, pp. 4–20.

52 Friedrich Nietzsche, "On Truth and Falsity in their Ultramoral Sense," in *The Complete Works of Friedrich Nietzsche*, ed. Oscar Levy, and trans. Maximilian A. Mugge, 16 vols. (New York: Macmillan, 1924), II: 178.

53 Nietzsche, "On Truth and Falsity," p. 180.

54 Wallace Stevens *The Necessary Angel: Essays on Reality and the Imagination* (New York: Vintage Books, 1951), p. 71.

55 A good metaphor, says Aristotle, "implies an intuitive perception of the similarities in dissimilar" (*Poetics*, 1459a).

56 Wallace Stevens, "Three Academic Pieces," in *The Necessary Angel*, p. 72.

57 Hilda Doolittle (H.D.), "Oread," in *Modern American Poetry, Modern British Poetry*, ed. Louis Untermeyer (New York: Harcourt, Brace and Co., 1950), p. 356.

58 Marcus B. Hester, "Metaphor and Aspect Seeing," *Journal of Aesthetics and Art Criticims* 25 (1966): 205–212.

58 George Lakoff and Mark Johnson, "Conceptual Metaphor in Everyday Language," reprinted in *Pilosophical Perspectives on Metaphor*, ed. Johnson, pp. 286–329.

60 *Philosophical Perspective on Metaphor*, ed. Johnson, p. 31.

61 Hesse has argued forcefully for a cognitive function for both models and metaphors. She says, for example:

> Acceptance of the view that metaphors are meant to be intelligible implies rejection of all views that make metaphor a wholly noncognitive, subjective, emotive, or stylistic use of language. These are exactly parallel views of scientific models that have been held by many contemporary philosophers of science, namely that models are purely subjective, psychological, and adopted by individuals for private heuristic purposes. But this is wholly to misdescribe their function in science. Models, like metaphors, are intended to communicate. (*Models and Analogies in Science*, pp. 164–165).

62 C.S. Lewis "Bluspels and Flalansferes," in *The Importance of Language*, ed. Max Black (Englewood Cliffs, NJ: Prentice-Hall, 1962), pp. 37–38.

63 For a discussion of the role of novelty and freshness in all good poetry, see Daniel Burke, *Notes on Literary Structure* (Washington, D.C.: University Press of America, 1982) pp. 27–49. A detailed discussion can be found there of a refreshing characterization of a poet's wife as a "breathtakingly levelheaded girl." There is an anomalous quality to calling a wife "breathtakingly levelheaded." Anomalies like these can best be characterized by metaphors. This point has been brought out earlier by the Russian and Czech formalist theories of "foregrounding." See Jan Mukarovsky, "Standard Language and Poetic Language," in *A Praque School Reader on Esthetics, Literary Structure, and Style*, ed. and trans. Paul L. Garvin (Washington,

D.C.: Georgetown University Press, 1964), p. 19; see also Burke, *Notes on Literary Structure*, pp. 28–32.

64 Ina Loewenberg, "Truth and Consequences of Metaphors," *Philosophy and Rhetoric* 6, (1973): 44.

65 Kuhn. *The Structure of Scientific Revolutions*, p. 121. See my discussion of Kuhn's position on gestalt switches in "Scientific Revolutions," pp. 22–26.

66 Quoted in Norwood Hanson's *Patterns of Discovery* (Cambridge: Cambridge University Press, 1958), p. 184.

67 W.H. Newton-Smith, *The Rationality of Science* (Boston and London: Routledge and Kegan Pual, 1981), p. 118.

68 For an interesting survey of the structuralist literature and its application to philosophy of science, see Walter Creed, "Philosophy of Science and Theory of Literary Criticism: Some Common Problems," *PSA 1980: Proceedings of the 1980 Biennial Meeting of the Philosophy of Science Association*, ed. Peter Asquith and Ronald N. Giere, 2 vols. (East Lansing, MI: Philosophy of Science Association, 1980), 1: 131–140. Creed captures the essential elements of the structuralist approach when he states: "The structuralist is not concerned with the mystery or with its resolution, but with those elements of the narrative, the codes, that enable him to read the clues as clues and not simply as miscellaneous narrative details . . .. Learning to recognize and interpret these codes requires reading a number of novels and becoming aware if only tacitly of their existence and function" (p. 133).

69 George G. Grabowicz, "A Consideration of Deep Structures in Shevchenko's Works," in *Shechenko and the Critics, 1861–1980*, ed. George S.N. Luckyi (Toronto: University of Toronto Press, 1980), pp. 481–497. For a more thorough discussion, see Grabowicz's recent book, *The Poet as Mythmaker: A study of Symbolic Meaning in Taras* Ševčenko, Harvard Ukrainian Research Institute, 1982.

70 Grabowicz, "A Consideration of Deep Structures," pp. 491–92.

71 Grabowicz, "A Consideration of Deep Structures," p. 490.

72 Paul Feyerabend, *Against Method* (Atlantic Highlands, NJ: Humanities Press, 1975).

73 Authors who want to bring mythological and scientific thinking closer together include: Ian G. Barbour, *Myths, Models, and Paradigms* (New York: Harper and Row, 1974), particularly chap. 2, "Symbol and Myth"; E.R. MacCormac, *Metaphor and Myth in Science and Religion* (Durham, NC: Duke University Press. 1976). A particularly exciting discussion of myth in science can be found in Bernard d'Espagnat*A La Recherche du Réel: Le Regard d'un Physicien* (Paris: Gauthier-Villars, 1979).

74 Quoted in Rothenberg's, "Creative Contradictions," p. 59.

75 Robert Lowell's response to commentaries on his poem "Skunk Hour," in *The Contemporary Poet as Artist and Critic: Eight Symposia*, ed. Anthony Ostroff (Boston: Little, Brown, 1964), p. 109.

76 For a discussion of the role of paragons in the creation of paradigm-theories in science, see my "Scientific Revolutions," pp. 71–94. The chapter contains a rational reconstruction of Kuhn's *The Structure of Scientific Revolutions*, together with a definition of paradigms and paragons.

77 Cleanth Brooks and Robert Penn Warren describe this kind of borrowing further: "Though the poet must finally work out a form for each particular poem, this does not mean that he may not make use of elements of form handed from other poets – elements such as metrical patterns, symbols, and ways of relating images to theme, etc. Such elements when their use has become fixed and recognized, are called conventions" (*Understanding Poetry*, 3rd ed. [New York: Holt, Rinehart and Winston, 1960], Glossary s.v. "convention").

78 For a discussion of these and other constraints, see Burke, *Notes on Literary Structure*, p. 53.

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